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JP 2000134713 A   US 5915801 A

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(54) Abstract Title
Transmission responsive regenerative braking

(57) A regenerative brake control system improves the drivability of a hybrid electric vehicle by adjusting the brake torque in response to the degree of engine connection. The clutch 24 separates the engine 20 from the motor 22 to enable increased energy accumulation in the battery during braking. As the clutch opens, the braking torque is increased towards a target torque. The system disconnects the clutch in response to parameters including the driver braking demand, the vehicle speed, the accelerator position, the charge level of the battery and the operating status of the vehicle and the motor.
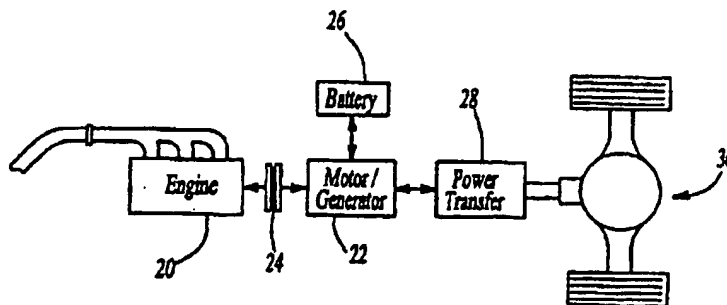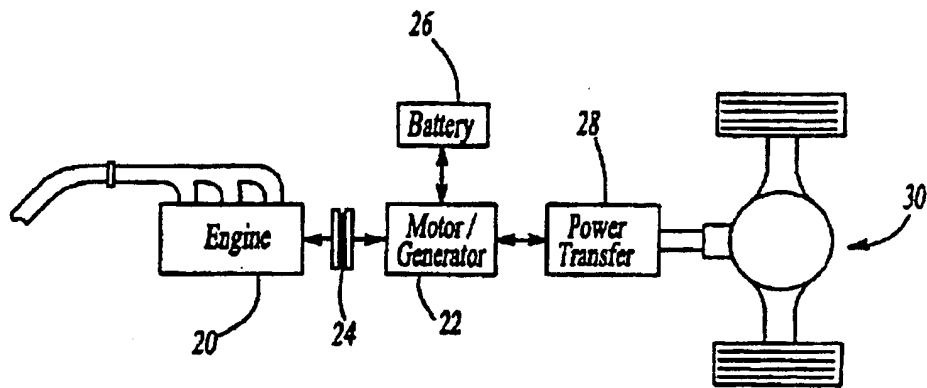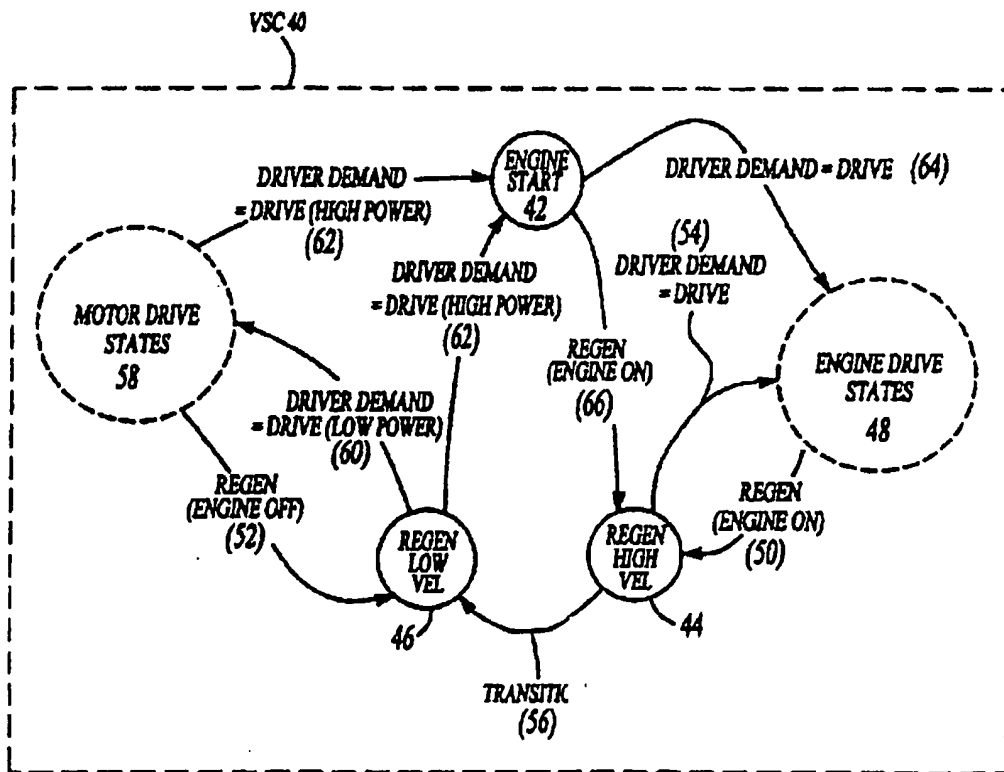

Fig-1

GB 2 368 827 A

Fig-1

Fig-2

METHOD AND SYSTEM FOR COLLECTING
REGENERATIVE BRAKING ENERGY IN
A PARALLEL HYBRID ELECTRIC VEHICLE

5   The present invention relates generally to a hybrid electric vehicle, and specifically to a method and system to optimize collecting regenerative braking energy in a parallel hybrid electric vehicle (HEV) while minimizing torque disturbance to the powertrain.

10

The need to reduce fossil fuel consumption and pollutants from automobiles and other vehicles powered by an internal combustion engines (ICE's) is well known. Vehicles powered by electric motors have attempted to address these

15   needs. However, electric vehicles have limited range and limited power coupled with the substantial time needed to recharge their batteries. An alternative solution is to combine both an ICE and electric traction motor into one vehicle. Such vehicles are typically called hybrid electric

20   vehicles (HEV's). See generally, U.S. Pat. No. 5,343,970 (Severinsky).

The HEV has been described in a variety of configurations. Many HEV patents disclose systems where an

25   operator is required to select between electric and internal combustion operation. In other configurations the electric motor drives one set of wheels and the ICE drives a different set.

30   Other, more useful, configurations have developed. A series hybrid electric vehicle (SHEV) is a vehicle with an engine (most typically an ICE) which powers a generator. The generator, in turn, provides electricity for a battery and motor coupled to the drive wheels of the vehicle. There

35   is no mechanical connection between the engine and the drive wheels. A parallel hybrid electrical vehicle (PHEV) is a vehicle with an engine (most typically an ICE), battery, and

electric motor combined to provide torque to power the wheels of the vehicle.

A parallel/series hybrid electric vehicle (PSHEV) has characteristics of both the PHEV and the SHEV. The PSHEV is also known as a torque (or power) splitting powertrain configuration. Here, the torque output of the engine is given in part to the drive wheels and in part to an electrical generator. The generator powers a battery and motor that also provide torque output. In this configuration, torque output can come from either source or both simultaneously. The vehicle braking system can even deliver torque to drive the generator to produce charge to the battery.

The desirability of combining the ICE with an electric motor is clear. The ICE's fuel consumption and pollutants are reduced with no appreciable loss of performance or range of the vehicle. Nevertheless, there remains substantial room for development of ways to optimize the HEV's operational parameters. Two such areas of development are engine start/stop and regenerative braking. Engine start/stop strategies turn off the engine during times of low power demand from the driver, thereby reducing fuel usage and emission production directly.

Regenerative braking (regen) captures the kinetic energy of the vehicle as it decelerates. In conventional vehicles, kinetic energy is usually dissipated as heat at the vehicle's brakes or engine during deceleration. Regen converts the captured kinetic energy through a generator into electrical energy in the form of a stored charge in the vehicle's battery. This stored energy is used later to power the electric motor. Consequently, regen also reduces fuel usage and emission production. In certain vehicle configurations, the engine can be disconnected from the rest

of the powertrain thereby allowing more of the kinetic
energy to be converted into stored electrical energy.

Successful implementation of an efficient regen
strategy must consider, among other things, the effects of
ICE braking on the vehicle. In conventional vehicles,
engine braking is well known and is typically characterized
by two types of negative powertrain torques including engine
friction and pumping losses. Both types of losses result
from the engine being driven by the wheels through the
powertrain. Engine friction losses result from the piston
rings sliding along the cylinder walls and rotation in the
bearings of the engine. Engine pumping refers to the
compression of the air in each of the engine's cylinders as
the engine moves through its stroke. Engine braking allows
the driver to reduce vehicle speed without applying force to
the brake pedal.

Regenerative braking (regen) is known for conventional
ICE vehicles in the prior art. A primitive regen system is
described in U.S. Pat. No. 5,086,865 to Tanaka, et. al. In
Tanaka, a regen controller decouples the engine from the
vehicle's powertrain. Based on vehicle speed and gear
selection, an electromagnetic clutch couples the powertrain
to a hydraulic pump/motor whereby the vehicle's kinetic
energy is transferred to a high pressure oil accumulator.
The pressure can be transferred back to the powertrain
during, for example, the next acceleration of the vehicle.

Regen in an HEV is also known in the prior art. In U.S.
Pat. No. 5,839,533 to Mikami, et. al., a rapid response
drive source brake controller for engine braking and regen
is described. The Mikami controller determines the
gearshift lever position manually set by the driver (e.g.,
low gear). The engine's brake force (negative torque)
increases as the speed ratio of an automatic transmission
increases. The controller can engage both engine braking

and regenerative braking if the manually selected braking exceeds the maximum regen force that can be generated by the electric generator.

5   Taga, et. al., U.S. Pat. No. 5,915,801, discloses a regen controller to simulate ICE braking torque. This controller disengages the engine from the powertrain via a disconnect clutch and accumulates braking energy (negative torque) in an on-board accumulator such as a generator and
10   battery. The Taga controller improves the speed and efficiency of the regen by, for example, determining the target braking torque according to the release speed of the accelerator petal. Thus, when large braking torque is required, the controller makes it possible to produce a
15   large amount of regen without delay even before the brake pedal is depressed. This decreases the need for the driver to operate the manual shift lever to a lower gear or further depress the brake pedal. The controller can additionally use input from brake pedal position, vehicle speed, vehicle
20   weight, and gradient information to determine target braking torque.

       Using the Taga controller during regen, the engine may or may not be connected to the powertrain. If the engine is
25   disconnected during regen, there is no engine friction and pumping. This allows the recapture of even more kinetic energy without exceeding the deceleration limits for the vehicle. Obviously this is advantageous for an HEV from an energy management perspective.

30

       The trade-off for disconnecting the engine to capture more regen energy is that with the engine disconnected, the transition back to an engine driving state becomes significantly more complex. If the engine is left connected
35   during regen and the driver depresses the accelerator pedal, it is a straightforward process to restart the engine, if desired, simply by reinitializing fueling of the engine.

Any torque disturbance to the powertrain due to the engine restarting would be small, and not completely unexpected by the driver, given the change in demand. Alternatively, if the engine is disconnected from the powertrain during regen,

5 starting the engine would involve maintaining the vehicle's response to the driver's demand using the motor while simultaneously closing the disconnect clutch and starting the engine.

10 Torque supply to the powertrain should be transferred from the motor to the engine smoothly in order to avoid any disturbance to the driver. Nevertheless, the Taga patent, while attempting to simulate engine braking and improve vehicle drivability, does not address the common situation

15 where a driver suddenly changes from decelerating to accelerating.

It is an object of the invention to provide improved control of regenerative braking to overcome the problems

20 associated with the prior art.

According to a first aspect of the invention there is provided a method for controlling regenerative braking of a vehicle, the method comprising the steps of, determining a

25 target braking torque based on a basic quantity which is at least one of, a driver demand and a vehicle operating status, determining whether to disconnect a connector of an engine to a vehicle powertrain, whereby increased regenerative braking energy can be collected; and

30 controlling a resultant increasing regenerative braking torque during an engine disconnect thereby minimising powertrain disturbance.

The determination of driver demand may comprise the

35 steps of, determining a brake pressure position and determining an accelerator position.

The determination of vehicle operating status may comprise the steps of determining an engine on status, determining a battery state of charge, determining a transmission gear, determining a transmission shift status, determining a battery current sink capability, determining a motor fault condition and determining a vehicle speed.

The method may comprise the additional steps of, determining whether to disconnect the connector of the engine to the vehicle powertrain, whereby increased regenerative braking energy can be collected, and controlling the resultant increasing regenerative braking torque during engine reconnect to assist with minimising powertrain disturbance.

The determination of whether to disconnect the connector of the engine to the vehicle powertrain may comprise the steps of, determining whether a predetermined vehicle speed has been reached and determining that no fault conditions exist in a vehicle motor.

The minimising of powertrain disturbance during disconnection of the engine connector with the vehicle powertrain may comprise the steps of measuring continuously the amount of connection between the vehicle powertrain and the engine connector and compensating continuously the amount of regenerative braking according to the amount of engine torque and the amount of connection.

According to a second aspect of the invention there is provided a control system for controlling regenerative braking of a vehicle, the system comprising a controller programmed to determine a target braking torque based on a basic quantity which is at least one of, a driver demand and a vehicle operating status, to disconnect a connector of an engine to a vehicle powertrain, whereby increased regenerative braking energy can be collected and to increase

regenerative braking torque during an engine disconnect thereby minimising powertrain disturbance.

The driver demand may be determined by providing signals indicative of brake pressure and accelerator position to the controller.

The vehicle operating status may be determined by providing signals to the controller indicative of engine on status, whether a motor fault condition exists, vehicle speed, battery state of charge, a transmission gear selected, transmission shift status and the battery current sink capability.

The controller may be further programmed to determine whether to disconnect the engine connector to the vehicle powertrain, whereby increased regenerative braking energy can be collected and to control the resultant increasing regenerative braking torque during engine disconnect to minimize powertrain disturbance.

The controller may be operable to determine whether to disconnect the engine connector to the vehicle powertrain by determining whether a predetermined vehicle speed has been reached and confirming that a no fault conditions exist in a vehicle motor.

The controller may be operable to continuously measure the amount of connection between the vehicle powertrain and the engine and continuously vary the amount of regenerative braking according to the amount of engine torque and the amount of connection.

The invention will now be described by way of example with reference to the accompanying drawing of which:-

Fig.1   is a schematic view of a Hybrid electric vehicle; and

Fig.2   is a schematic chart of a strategy used by a controller according to the invention.

The present invention generally relates to hybrid electric vehicles (HEV's). Although the preferred embodiment described is for a parallel HEV, the invention could be applied to any vehicle using a motor and an engine as the drive source having an engine disconnect clutch.

Figure 1 shows general components of a parallel HEV powertrain with an engine disconnect clutch. An engine 20, is linked to a motor/generator 22, via a disconnect clutch 24. A battery 26 connects to the motor/generator 22 to allow the flow of electrical current to and from the two components. The motor/generator 22 is connected to a powertrain (power transfer unit) 28, such as a transmission or driveshaft, which is connected to the vehicle's wheels 30. Thus, torque energy flows from the engine 20 and motor/generator 22 through the power transfer unit 28 to the wheels 30.

Since the engine 20 can be disconnected from the motor/generator 22 and power transfer unit 28, there are two potential drive states for the regen. The present invention establishes a strategy to determine whether to acquire more regenerative energy (engine disconnected) or to allow quick driver changes of demand (engine connected).

This two state strategy is shown in Figure 2, the MOTOR DRIVE state 58 represents all of the (non-regen) states in the vehicle for which the disconnect clutch is disconnected. ENGINE DRIVE state 48 represents all of the (non-regen) states for which the disconnect clutch is connected.

If a vehicle system controller (VSC) 40 requests regen (based on driver demand and vehicle operating status), either a REGEN HIGH VEL state 44 or REGEN LOW VEL state 46 will be reached depending on the a previous state of the VSC

5   40. Various variables of vehicle operating status are possible. These can include: vehicle speed, engine 20 on status, motor/generator 22 fault condition, battery 26 state of charge, battery 26 sink capability, and power transfer unit 28 component status such as transmission gear and

10   transmission shift. The battery sink capability is the ability of the battery 26 to absorb additional charge.

If the VSC 40 is in one of the ENGINE DRIVE state 48 and the transition conditions represented by REGEN (ENGINE

15   ON) 50 are satisfied, the VSC 40 will transition to a REGEN HIGH VEL state 44. In this state, the disconnect clutch 24 remains closed, keeping the engine 20 connected to the motor/generator 22 and power transfer unit 28.

20   In this state, regenerative braking torque commanded to the motor/generator 22 by the VSC 40 is reduced by the amount of the braking torque delivered to the power transfer unit 28 by the engine 20. Conversely, if the VSC 40 is in one of the MOTOR DRIVE state 58 and the transition

25   conditions represented by REGEN (ENGINE OFF) 52 are satisfied, the VSC 40 will transition to the REGEN LOW VEL state 46.

In this state, the disconnect clutch 24 remains open,

30   keeping the engine 20 disconnected from the motor/generator 22 and power transfer unit 28. In this state, full regenerative braking torque can be commanded to the powertrain because no engine braking needs to be accounted for.

35

In short, when the VSC 40 first enters a regen mode, if the engine 20 is connected to the powertrain through the

disconnect clutch 24, it remains connected (initially) when the regen mode is entered.

Once in REGEN HIGH VEL state 44, the VSC 40 can transition back to the ENGINE DRIVE state 48 if requested by a change in driver demand, DRIVER DEMAND = DRIVE 54, by simply fuelling the engine 20 appropriately and eliminating a regen torque command to the motor/generator 22. This is easily accomplished since the disconnect clutch 24 is already closed, keeping the engine 20 connected to the powertrain.

The transition from REGEN HIGH VEL state 44 to REGEN LOW VEL state 46 is based on vehicle speed and the motor/generator 22 status. A transition 56 is allowed once the vehicle speed falls below a calibratable value, assuming that the motor/generator 22 is not in a fault condition (which could prevent it from being used to restart the engine). A more sophisticated strategy for the transition 56 condition might also incorporate a vehicle's brake pedal pressure or position as an indicator of the likelihood that the driver might change powertrain torque demand.

The strategy also accounts for transitions into and out of the MOTOR DRIVE state 58. If the vehicle is in the MOTOR DRIVE state 58, (i.e., engine 20 not connected or running), only the REGEN LOW VEL 46 mode can be entered directly. Once in REGEN LOW VEL state 46, the system can transition back to the MOTOR DRIVE state 58 if the driver demands a relatively low level of positive torque to the wheels, DRIVER DEMAND = DRIVE (LOW POWER) 60. In the case of a high level of torque demand to the wheels, DRIVER DEMAND = DRIVE (HIGH POWER) 62, the system would initiate an ENGINE START state 42 event and then would transition to an ENGINE DRIVE state 48 assuming that the transition condition, DRIVER DEMAND = DRIVE 64, is satisfied. In no instance would a transition directly from REGEN LOW VEL state 46 to REGEN

HIGH VEL state 44 be allowed without first starting the engine 20. If the driver demand changed while the VSC 40 was in the ENGINE START state 42, a transition REGEN (ENGINE ON) 66 to REGEN HIGH VEL state 44 would be allowed once an
5 ENGINE START state 42 event was completed.

The total amount of available drive source braking torque (deceleration) (at the motor/generator 22) is specified in a calibratable table and is dependent on
10 several factors including current gear ratio, vehicle speed, brake pressure, motor/generator 22 capability, and motor/generator 22 speed. Levels are calibrated to achieve desired performance feel during deceleration (either braking or coasting). In the REGEN HIGH VEL state 44 (disconnect
15 clutch 24 connected), the total level of drive source braking torque commanded to the motor/generator 22 must be reduced by the amount of negative drive source torque from the engine's 20 friction and pumping:

20 $$\tau mot\_cmd = \tau tot - \tau eng,$$

where:-
τmot_cmd is the commanded regen torque to the motor/generator 22,
25 τtot is the calibrated torque (total allowable depending on the current vehicle operating conditions), and τeng is the engine friction and pumping torque.

In the REGEN LOW VEL state 46, the output command is
30 more complicated. When the state is first entered, the disconnect clutch 24 is still engaged so the engine 20 is still providing negative torque to the powertrain from pumping and friction. Within the state, the disconnect clutch 24 is commanded to open, which reduces negative
35 torque on the motor/generator 22 and power transfer unit 28 (powertrain). To avoid a noticeable powertrain disturbance, this reduction of negative engine 20 torque is replaced with

equal increases in regen torque from the motor/generator 22, even during the transition. This is accomplished by increasing the negative torque commanded to the motor/generator 22 according to an estimated amount of the reduction in the torque being passed through the disconnect clutch 24 from the engine 20.

There are several ways to estimate the amount of torque reduction from the engine 20. One method uses the relative position of the clutch plates. The formula for the motor/generator 22 torque command for this method is:

$$\tau mot\_cmd = \tau tot - \lambda(xc)\tau eng,$$

where:-
$\lambda(xc)$ is the percent fully closed of the disconnect clutch 24 and is given by:

$$\lambda(x_c) = 1 - \frac{x_c - x_{fc}}{x_{fo} - x_{fc}}$$

where:-
xc is the position of a disconnect clutch plate,
xfc is the fully closed position of the plate, and
xfo is the fully open position of the plate.

In the formula above, $\lambda(xc)$ is a linear function of xc.

In general, for alternative implementations, other more general nonlinear functions might better represent the relationship between clutch plate position and percent torque passed through the clutch. Although the algorithm above uses clutch plate position to determine the percent of engine friction and pumping torque that the clutch is passing to the powertrain, alternative algorithms could use

other measures to determine this value. One obvious
alternative choice would use disconnect clutch 24 apply
pressure. During clutch apply, the amount of torque passed
through the clutch is a function of this pressure. In other
5   words,

$$\tau cl = f(pcl).$$

In this case, the motor/generator 22 torque command
10   would be calculated according to:

$$\tau mot\_cmd = \tau tot - \tau cl,$$

where:-
15   τcl is the signal from the disconnect clutch 24
measured by cylinder pressure.

CLAIMS

1. A method for controlling regenerative braking of a vehicle, the method comprising the steps of, determining a target braking torque based on a basic quantity which is at least one of, a driver demand and a vehicle operating status, determining whether to disconnect a connector of an engine to a vehicle powertrain, whereby increased regenerative braking energy can be collected; and controlling a resultant increasing regenerative braking torque during an engine disconnect thereby minimising powertrain disturbance.

2. A method as claimed in claim 1, wherein determining driver demand comprises the steps of, determining a brake pressure position and determining an accelerator position.

3. A method as claimed in claim 1 or in claim 2 wherein determining vehicle operating status comprises the steps of determining an engine on status, determining a battery state of charge, determining a transmission gear, determining a transmission shift status, determining a battery current sink capability, determining a motor fault condition and determining a vehicle speed.

4. A method as claimed in any of claims 1 to 3 comprising the additional steps of, determining whether to disconnect the connector of the engine to the vehicle powertrain, whereby increased regenerative braking energy can be collected, and controlling the resultant increasing regenerative braking torque during engine reconnect to assist with minimising powertrain disturbance.

5. A method as claimed in claim 4 wherein determining whether to disconnect the connector of the engine to the vehicle powertrain comprises the steps of, determining

whether a predetermined vehicle speed has been reached and
determining that no fault conditions exist in a vehicle
motor.

5   6.   A method as claimed in any of claims 1 to 5
wherein minimising powertrain disturbance during
disconnection of the engine connector with the vehicle
powertrain comprises the steps of measuring continuously the
amount of connection between the vehicle powertrain and the
10   engine connector and compensating continuously the amount of
regenerative braking according to the amount of engine
torque and the amount of connection.

7.   A control system for controlling regenerative
15   braking of a vehicle, the system comprising a controller
programmed to determine a target braking torque based on a
basic quantity which is at least one of, a driver demand and
a vehicle operating status, to disconnect a connector of an
engine to a vehicle powertrain, whereby increased
20   regenerative braking energy can be collected and to increase
regenerative braking torque during an engine disconnect
thereby minimising powertrain disturbance.

8.   A system as claimed in claim 7 wherein the driver
25   demand is determined by providing signals indicative of
brake pressure and accelerator position to the controller.

9.   A system as claimed in claim 7 or in claim 8
wherein the vehicle operating status is determined by
30   providing signals to the controller indicative of engine on
status, whether a motor fault condition exists, vehicle
speed, battery state of charge, a transmission gear
selected, transmission shift status and the battery current
sink capability.

35

10.   A system as claimed in any of claims 7 to 9 in
which the controller is further programmed to determine

whether to disconnect the engine connector to the vehicle powertrain and to control the resultant regenerative braking torque during engine disconnect to minimise powertrain disturbance.

5

11.   A system as claimed in claim 10 wherein the controller is operable to determine whether to disconnect the engine connector to the vehicle powertrain by determining whether a predetermined vehicle speed has been

10   reached and confirming that a no fault conditions exist in a vehicle motor.

12.   A system as claimed in claim 10 or claim 11 wherein the controller is operable to continuously measure

15   the amount of connection between the vehicle powertrain and the engine and continuously vary the amount of regenerative braking according to the amount of engine torque and the amount of connection.

20   13.   A method for controlling regenerative braking of a vehicle substantially as described herein with reference to the accompanying drawing.

14.   A control system for controlling regenerative

25   braking of a vehicle substantially as described herein with reference to the accompanying drawing.

The Patent Office

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Application No:	GB 0123914.4	**Examiner:**	Mark Thwaites
Claims searched:	1 to 14	**Date of search:**	9 January 2002

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): B7H   HDE ,   HXD

Int Cl (Ed.7): B60K 41/24 ; B60L 7/10, 11/12 ; B60T 1/10

Other: Online: EPODOC, WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	US 5915801 A (TAGA) Whole document	
A	JP 2000134713 A (TOYOTA) Abstract	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier
&	Member of the same patent family		than, the filing date of this application.